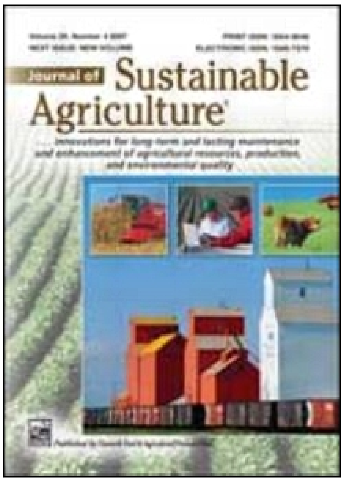

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Soil Conservation Benefits of Large Biomass Soybean (LBS) for Increasing Crop Residue Cover

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Soil Conservation Benefits of Large Biomass Soybean (LBS) for Increasing Crop Residue Cover

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ABSTRACT. Soybeans are planted on approximately eight million hectares (20 M acres) of highly erodible land (HEL) in the United States. Soybean crops have been recognized as deficient in supplying crop residues that reduce soil erosion. A new type of soybean tested at the Beltsville Agricultural Research Center, Maryland, can grow to heights of 1.8-meters (6 ft) or more. The development of the large biomass soybean (LBS) suggested the potential of increased crop residue production to reduce soil loss on erodible soybean lands. An evaluation was conducted of the soil conservation benefits of LBS versus conventional soybean using data from a three-year field experiment. LBS produced more crop residue dry biomass and provided a mean increase of 31 percent more crop residue cover in the spring before mulch tillage and 47 per-

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cent more after mulch tillage than conventional cultivars. Soil loss estimates for LBS were much lower than for conventional soybeans as simulated by a revised universal soil loss equation (RUSLE). Breeding for increased residue production in soybeans could produce significant environmental benefits as a soil conservation practice in reducing soil erosion. The conservation benefits of LBS can be realized if enhanced biomass production can be combined with adequate grain production.

KEYWORDS. Soil erosion, revised universal soil loss equation (RUSLE), carbon sequestration

INTRODUCTION

The potential of new and better soybean types for soil conservation are being explored at the USDA Beltsville Agricultural Research Center (BARC) in Beltsville, Maryland. A new type of soybean, called large biomass soybean (LBS), is now being bred by scientists at BARC to produce high crop residues as well as improved grain yields. Some experimental LBS lines under study can grow as tall as 1.8 meters (6 ft) or more and contribute increased biomass compared to conventional cultivars grown in Maryland (Figure 1). Three LBS cultivars have been released for use as a high protein forage crop (Devine and Hatley, 1998a; Devine et al., 1998b, 1998c). Although, the LBS lines were originally developed for forage, these same LBS types or additional ones bred for improved grain production might be useful in increasing crop residues on soybean lands. The increased biomass production of the forage cultivars suggested the possibility of developing grain type LBS lines with increased crop residue production.

Crop residue on the soil surface reduces the impact of raindrops and the lateral movement of soil particles. Adequate crop residue management, as a conservation practice, requires the presence of higher amounts of crop residues on highly erodible land (HEL) after harvest, and the persistence of the residues through the next planting season. Persistence of the crop residues is benefitted by decreased decomposition and reduced breakage and burying during tillage. It is estimated by the Natural Resources Conservation Service (NRCS) that approximately 8.1 million hectares (20 million acres) of soybean are planted on HEL in United States (U.S.) soybean producing regions. Growers participating in federal farm programs must have soil conservation plans in place. Crop residue management is a conservation practice which can be employed to meet the soil conservation requirement on HEL. To reduce soil erosion on

FIGURE 1. Growth of conventional soybean compared to large biomass soybean.

HEL, conservationists "as a general rule of thumb" recommend that the soil surface should retain greater than 30 percent coverage of crop residue through the planting of the next crop. This percentage can vary according to region, location, soil type, and other supporting conservation practices and factors. Conventional types of soybean crop cultivars have been recognized as deficient in supplying crop residues that can reduce soil erosion (McMurtrey and Devine, 1997). The LBS could assist in achieving crop residue coverage goals on the nation's soybean lands.

The U.S. is the world's principal soybean producing and processing nation. In 1998, U.S. farmers harvested more than 28 million hectares (69 million acres) of soybeans or 41 percent of the total world production area. Soybean production in the U.S. was 75 million metric tons (82.7 U.S. tons) of grain or 47 percent of the total world production (FAO, 1999), and U.S. processors produced more than 8 million metric tons (8.8 U.S. tons) of soybean oils, or 36 percent of the world total. U.S. domestic soy-based food markets have been growing at double-digit rates, and international demand for soybeans has grown continuously as Asian economies improve (Lee, 1997; MSGA, 1998; Bangsund and Leistritz, 1999). In the U.S., soybean consistently ranks third, after corn and wheat, in the number of hectares (acres) planted (USDA, 1997, 1998 and 1999).

HEL conservation issues have been addressed by the U.S. Congress in all three of the latest farm bills. The Food Security Act of 1985 (FSA85) tied public concerns over environmental quality to the eligibility for Federal commodity program benefits through conservation provisions. Soil conservation compliance, one of the landmark conservation provisions, targets approximately 65 million hectares (161 million acres) of HEL in the U.S. To be eligible for Federal farm programs, the FSA85 required farmers with fields classified as highly erodible to develop conservation plans for their farms by the end of 1989, and to fully implement these plans by the end of 1994. Conservation options on HEL may include environmentally beneficial crop rotations, tillage systems and practices, or taking that land out of agricultural production. The conservation compliance requirements, as part of the FSA85, are re-authorized in the Food, Agricultural, and Conservation Act of 1990 (FACT90), and the Federal Agricultural Improvement and Reform Act of 1996 (FAIR96). As small grain crops of winter and spring wheat and barley suffered yield, price, and quality problems in the early 1990s, U.S. growers have been seeking other crops for profitability. Small grain and corn crops require nitrogen fertilizers, and have caused environmental concerns on issues involved in nitrogen pollution and water quality. The legume row crop soybean has offered an attractive alternative to small grains and corn for many growers (Bangsund and Leistritz, 1999). However, there are particular concerns where soybean farming is conducted on steeply sloped land since soybean crops contribute less to the accumulation of crop residue than other major hectare (acreage) crops.

The objective of this study is to compare soil conservation impacts of LBS versus conventional soybean using data and information from a multi-year field experiment. The field experiment for testing soybean lines for crop residue production started in 1994. The purpose of the experiments was to evaluate and identify LBS germplasm types emerging from a breeding program and to develop an improved soybean that would provide enhanced crop residues with a yield level comparable to conventional soybean cultivars. The soil conservation effectiveness of LBS was evaluated by an estimate of the long-term mean annual rate of soil loss simulated by using the Revised Universal Soil Loss Equation (RUSLE) (USDA, 2003 and Foster et al., 1996). Reducing soil erosion not only contributes to achieving the conservation goal of mitigating the damage to onsite productivity but also the environmental goal of ameliorating offsite sediment damage. The RUSLE was used to calculate a simulated soil loss from data acquired on small experimental field plot plantings of LBS soybeans versus conventional soybean crops.

FIELD EXPERIMENT MATERIALS AND METHODS

Test assessments for experimental soybean lines with increased crop residues were conducted at BARC in Beltsville, Maryland in 1994, 1995, and 1998. The tests have contained up to 60 plots in a randomized complete block design on a contour across the 5 percent slope of the field. The plots were separated by 2.2 meter (7 ft) bare soil alleyways. The soil in the test field was a Codorus silt loam. Over the 1994-98 period, average annual precipitation and temperature in the surrounding area of the test field was about 940 mm (37 inches) and 13ºC (55ºF), respectively. RUSLE was used on experimental test plot data to estimate soil loss from LBS and the typical conventional soybean types grown in Maryland.

Four replications were planted in each of the test years. The testing field was tilled with moldboard turn plowing in early May. This was followed by disking with a disk-harrow, re-disking, and culti-packing in late May. This produced a planting surface that was free of crop residue, with zero percent residue cover as the baseline soil condition. Soybeans were planted in 3.08 m (10 ft) long 4-row plots. Rows were 0.76 meter (30 inches) wide. Each soybean plot test area was small (3.08 m × 3.08 m) (10 ft × 10 ft) because only a small amount of LBS seeds for each breeding test line were available. The soybean crop was planted in early June of each year. Four conventional grain cultivars (Essex, Hutcheson, Spry, Williams-82) adapted to the mid-Atlantic states were used for comparison with the LBS lines. In 1994, five tall growing experimental lines were selected for the test. Test assessment consisted of eight LBS lines in 1995. In 1998, eleven LBS experimental lines were introduced for comparison with the conventional grain type cultivars. The number of LBS lines increased and some LBS lines changed as additional new experimental lines from advanced generations of selection from the breeding nurseries became available for testing in latter years.

Except for tillage, the typical cultural practices for conventional soybean crops in the mid-Atlantic region were followed. Fertilizer (P, K) applications were made according to the recommendations from the University of Maryland Agricultural Extension Service. Weeds were controlled by herbicides and hand hoeing to produce a cropping surface that would contain only soybean residue materials at harvest. Plant height was measured in late August or early September after the LBS lines reached their maximum height. All the test cultivars were harvested and threshed in the fall. Dry vegetative biomass and grain yields were determined at the time of harvesting. Dry vegetative biomass was weighed on the harvest day and returned to its respective plot area by spreading uniformly. A residue sample of approximately 500 grams (~1.1 lbs) was weighed, dried and re-weighed after drying to determine moisture percentage. The reported values of biomass and grain yield were adjusted for differences in moisture content.

The soil conservation effectiveness of LBS was evaluated by the level of soybean residue cover and crop residue biomass, and the annual rate of soil erosion as determined by RUSLE. The level of soybean residue cover was measured using the line point transect measuring method. The approach employs a 15.38 meter (50 ft) line with beads every 0.15 meter (6 inches). The line was zig-zagged across each 3.08 meter × 3.08 meter (10 ft × 10 ft) 4 row plot, so that the 15.38 meter (50 ft) beaded line transversed several times over the plot area (McMurtrey and Devine, 1997). Residue cover was measured before and after each plot was double disked. The two measurements of the residue level were conducted in the spring of each testing year. The level of soybean residues before double disking tillage operation measured the residue coverage after wintering. The measurement after double disking was used to simulate experimentally the effect of a "mulch-till like" system on the small-scale plots. This measurement represents residue coverage similar to that at planting time in the next year with a mulch tillage system. Each year's experimental field test site for planting was moldboard turn plowed to provide a planting surface free of crop residue.

The RUSLE was employed to compute average annual soil loss for each analytical scenario. RUSLE is a computer program widely used by NRCS to simulate average annual soil loss caused by rainfall and associated overland flow. It also displays a wide range of other values that provide insight into how conditions at a given site affect soil loss. The model represents the effects of the four major factors–climate, soil erodibility, topography, and land use–on soil movement. Cultural (C factor) and structural practices (P factor) are two essential types of practices estimated for control of soil loss. The main effect of the cover and management factor on soil loss is estimated using a subfactor approach. The subfactors considered in the cover and management factor are canopy cover, residue cover, soil random roughness, buried residue mass, live and dead root mass, and soil consolidation. These subfactors are a function of the type of crop, the level of crop production, and the manipulation of soil and crop components with tillage (Foster, 1999). RUSLE considers how these subfactors vary through the year in relation to temporal variations of rainfall erosivity annually.

This study estimated soil loss using the inputs of varying cover provided by different soybean lines as the management factor or the C-factor under average conditions in the State of Maryland for the RUSLE. All other RUSLE components were held constant. The rainfall and runoff factor of 180 for the Washington, D.C. area was used in this study because of the proximity to that location. An initial soil erodibility value of 0.344, adjusted for seasonal variability, was employed in the RUSLE simulation. The slope length and steepness factor of 1.134 was computed based on a 5 percent, 76.2-meter hill slope. The support practice (P) factor was set equal to 1. BARC test plot data from 1994, 1995, and 1998 for grain yields, residue biomass measurements, and residue coverage after tillage were used as inputs to compute C-factor values for various RUSLE soil loss simulation scenarios. The test plots produced no data in 1996 and 1997 due to weather conditions causing poor and uneven soybean germination in the experimental plot area.

EROSION ESTIMATE SCENARIOS FOR SOYBEAN

In the initial analysis of the experimental test plot data all agronomic character data from conventional soybean cultivars in the test plots across years were combined into one data set, and denoted conventional soybean by CONV and the large biomass by LBS. This CONV, LBS data was used to evaluate an average of the agronomic character performance for all the cultivars included in the field plot experiment (Tables 1a and 1b). Table 2 designates a 7-character acronym code assigned for soybean cultivars and experimental LBS lines that were used for RUSLE soil loss estimation scenarios. The various simulation scenarios are described in Table 3 for soil loss estimates for soybean lands and are to be used to interpret Tables 4a and 4b. Conventional soybean cultivar's averages from test plots of the highest, average, and lowest soil conservation performance data were also compared with the highest and average soil conservation performance of LBS lines under conventional and alternative tillage systems. In this RUSLE simulation experiment, conventional tillage (CT) is defined as a system that uses moldboard turn plowing, twice tandem disking, and conventional row soybean planting. Mulch tillage (MT) is defined as a field operation with light surface chisel plowing, finishing with light tandem disking and conventional row soybean planting. No-till (NT) system is defined as having no disturbing tillage operations except for the use of a no-till soybean planter. A base assumption was made that yield will not vary with tillage.

Initially, estimation scenarios were formulated in order to examine the conservation potential from LBS lines. In the first run of the RUSLE, all data on the conventional and LBS experimental lines in the plots across years were combined and composed into one data set to make means (xAVERxx) of the variables to run RUSLE. Soil loss estimates using the data from this LBS average data (LAVERxx) scenario were then compared to data averaged from all the conventional (CAVERxx) soybean cultivars in the test plots (Tables 4a and 4b). In the second block of Tables 4a and 4b, estimation strategies were designed to evaluate the conservation potential of experimental test plot LBS relative to the long term state average soybean crop grown in Maryland. The RUSLE was simulated with typical crop data for soybean grown in Maryland of 35 bushel/acre soybean yields (C35BUxx) and estimated, for instance, soil loss at 60.5 metric tons per hectare (27.0 U.S. tons/acre) under conventional tillage. This long-term yield scenario was selected as the baseline for comparison because conservationists in the NRCS would likely use this data to esti-

TABLE 1a. Agronomic characters of conventional vs. large biomass soybean (metric units).

Soybean Type	Statistical Summary	Plant Height (cm)	Dry Biomass (MTH)[1]	Grain Yield (MTH)	Gross Returns ($/ha)	Crop Residue Spring[2] (%)	Crop Residue Spring[3] (%)
Measuring Date		*8/29/1994*	*11/30/1994*	*11/30/1994*	-	*2/8/1995*	*5/4/1995*
CONV	Maximum	101.3	8.80	4.54	916	70.33	17.00
	Average	94.4	7.35	3.97	798	51.42	13.38
	Minimum	88.8	5.44	3.18	640	39.33	9.25
LBS	Maximum	143.0	11.08	4.58	921	81.67	42.75
	Average	130.9	9.36	3.90	785	75.33	31.20
	Change(%)[4]	38.7	27.32	−1.8	−1.8	32	57
Measuring Date		*9/13/1995*	*11/21/1995*	*11/21/1995*	-	*4/11/1996*	*6/21/1996*
CONV.	Maximum	86.3	8.40	3.83	946	57.25	26.00
	Average	85.3	7.44	3.34	825	51.00	19.81
	Minimum	85.0	6.62	2.87	709	42.50	16.00
LBS	Maximum	142.5	11.47	3.65	902	84.00	45.50
	Average	124.7	9.44	3.12	768	70.94	38.28
	Change(%)[4]	46.2	26.94	−6.7	−6.7	28	48
Measuring Date		*7/23/1998*	*11/12/1998*	*11/23/1998*	-	*4/26/1999*	*5/17/1999*
CONV.	Maximum	76.3	11.74	5.43	983	61.25	21.25
	Average	68.5	10.87	5.11	926	50.25	17.20
	Minimum	60.0	9.84	4.83	877	44.75	15.00
LBS	Maximum	165.0	17.23	5.02	909	82.75	50.25
	Average	118.8	13.24	4.61	837	74.43	37.86
	Change(%)[4]	73.5	21.81	−9.8	−9.8	33	55
Three-Year Average							
CONV	Mean	82.7	8.55	4.14	850	50.89	16.80
LBS	Mean	124.8	10.68	3.88	797	73.57	35.78
	Change(%)[4]	50.8	24.87	−6.5	−6.5	31	47

Note: Experimental results for each conventional (CONV) and large biomass soybean (LBS) cultivars in each year, not reported here in the interest of space limitation.

[1]MTH = metric tons per hectare.

[2]The percentage crop coverage before double disking operation, which represents no tillage.

[3]The percentage crop coverage after double disking operation, which represents mulch tillage.

[4]Percentage change relative to average of all conventional versus LBS cultivars.

TABLE 1b. Agronomic characters of conventional vs. large biomass soybean (U.S. units).

Soybean Type	Statistical Summary	Plant Height (ft)	Dry Biomass (USTA)[1]	Grain Yield (USTA)	Gross Returns ($/a)	Crop Residue Spring[2] (%)	Crop Residue Spring[3] (%)
Measuring Date		*8/29/1994*	*11/30/1994*	*11/30/1994*	-	*2/8/1995*	*5/4/1995*
CONV	Maximum	3.32	3.93	2.03	371	70.33	17.00
	Average	3.10	3.28	1.77	323	51.42	13.38
	Minimum	2.91	2.43	1.42	259	39.33	9.25
LBS	Maximum	4.69	4.95	2.04	373	81.67	42.75
	Average	4.29	4.18	1.74	318	75.33	31.20
	Change(%)[4]	28	22	−1.8	−1.8	32	57
Measuring Date		*9/13/1995*	*11/21/1995*	*11/21/1995*	-	*4/11/1996*	*6/21/1996*
CONV	Maximum	2.83	3.75	1.71	383	57.25	26.00
	Average	2.80	3.32	1.49	334	51.00	19.81
	Minimum	2.79	2.96	1.28	287	42.50	16.00
LBS	Maximum	4.68	5.12	1.63	365	84.00	45.50
	Average	4.09	4.21	1.39	311	70.94	38.28
	Change(%)[4]	32	21	6.7	6.7	28	48
Measuring Date		*7/23/1998*	*11/12/1998*	*11/12/1998*	-	*4/26/1999*	*5/17/1999*
CONV	Maximum	2.50	5.24	2.42	398	61.25	21.25
	Average	2.25	4.85	2.28	375	50.25	17.20
	Minimum	1.97	4.39	2.16	355	44.75	15.00
LBS	Maximum	5.41	7.69	2.24	368	82.75	50.25
	Average	3.90	5.91	2.06	339	74.43	37.86
	Change(%)[4]	36	18	−9.8	−9.8	33	55
Three-Year Average							
CONV	Mean	2.72	3.82	1.85	352	50.89	16.80
LBS	Mean	4.09	4.77	1.73	329	73.57	35.78
	Change(%)[4]	34	20	−6.5	−6.5	31	47

Note: Experimental results for each conventional (CONV) and large biomass soybean (LBS) cultivars in each year, not reported here in the interest of space limitation.

[1]USTA = US tons per acre.

[2]The percentage crop coverage before double disking operation, which represents no tillage.

[3]The percentage crop coverage after double disking operation, which represents mulch tillage.

[4]Percentage change relative to average of all conventional versus LBS soybean cultivars.

TABLE 2. Acronym codes for soybean cultivars and experimental LBS germplasm lines.

Cultivar or Line	Code
NRCS typical Maryland soybean, standard used for RUSLE	C35BUxx*
Mean value of 4 conventional cultivars tested	CAVERxx
Mean value of 11 LBS lines tested	LAVERxx
Mean of conventional cultivar Hutcheson	CHUTCxx
Mean of conventional cultivar Wiliams-82	CWILMxx
Mean of LBS line PA-15, highest residue cover LBS	LPA15xx
Mean of LBS line OH-49, highest grain yield LBS	LOH49xx
Mean of LBS cultivar Tyrone, highest biomass LBS	LTYRNxx
Simulated "ideal" LBS combining data from best traits of LBS Lines	LIDEAxx

* First character indicates the soybean type (conventional or LBS).
Characters 2-5 indicate cultivar or experimental line.
Characters 5 and 7 (xx) are reserved for tillage method.

mate soil loss on these experimental test areas which have 0.76 meter (30 inch) row soybeans and are on productive soils in the State of Maryland.

Among all the LBS (Lxxxxxx) grown in the plots, the experimental line, PA-15 (LPA15xx), had the longest lasting residue levels when soybean residues were measured after a double disking operation that experimentally simulated mulch tillage on the test plots. The LBS cultivar Tyrone (LTYRNxx) produced the highest biomass, while the LBS line, OH-49 (LOH49xx), produced the highest yields. In addition to the average scenario, the LBS line associated with each highest-performing agronomic character was utilized to simulate an additional "ideal" LBS line for the purposes of RUSLE modeling evaluations. The "ideal" (LIDEAxx) designation represents a simulated virtual LBS soybean cultivar that combines traits for the highest conservation benefits. The "ideal" LBS cultivar was established from the experimental data by combining the trait of highest biomass found in the forage cultivar Tyrone, with the trait of highest residue coverage after a spring mulch tillage operation recorded for the LBS line PA-15. This "ideal" (LIDEAxx) LBS cultivar is a simulation of what we might expect in soil conservation performance if the best traits in the lines could be combined by plant breeding to produce a cultivar with high grain yield, high biomass production, and high residue coverage levels. We combined data for traits that were expressed by individual lines with the assumption that these traits can eventually also be combined by plant breeding into a superior LBS cultivar.

During testing years, the conventional soybean cultivar Hutcheson (CHUTCxx) produced the highest grain yield, biomass and residue levels (Performance = Highest) of all the conventional cultivars in the test plots. The conventional soybean cultivar Williams-82 (CWILMxx) produced the poorest

TABLE 3. Simulation scenarios for soil loss estimates with soybean crops.

		Scenario		
Code	Cultivar or Line*	Tillage	Performance	Trait
C35BUCT	Typical MD CONV	Conventional	Long-term Record	NRCS MD Standard
C35BUMT	Typical MD CONV	Mulch	Long-term Record	NRCS MD Standard
C35BUNT	Typical MD CONV	No-till	Long-term Record	NRCS MD Standard
CAVERCT	4 MD Cultivars CONV	Conventional	Exp. Average	Biomass, residue and yield
CAVERMT	4 MD Cultivars CONV	Mulch	Exp. Average	Biomass, residue and yield
CAVERNT	4 MD Cultivars CONV	No-till	Exp. Average	Biomass, residue and yield
LAVERCT	Large-Biomass, LBS	Conventional	Exp. Average	Biomass, residue and yield
LAVERMT	Large-Biomass, LBS	Mulch	Exp. Average	Biomass, residue and yield
LAVERNT	Large-Biomass, LBS	No-till	Exp. Average	Biomass, residue and yield
CHUTCCT	Hutcheson, CONV	Conventional	Highest	Biomass, residue and yield
CHUTCMT	Hutcheson, CONV	Mulch	Highest	Biomass, residue and yield
CHUTCNT	Hutcheson, CONV	No-till	Highest	Biomass, residue and yield
CWILMCT	Williams-82, CONV	Conventional	Lowest	Biomass, residue and yield
CWILMMT	Williams-82, CONV	Mulch	Lowest	Biomass, residue and yield
CWILMNT	Williams-82, CONV	No-till	Lowest	Biomass, residue and yield
LPA15CT	PA-15, LBS	Conventional	Highest	Residue cover
LPA15MT	PA-15, LBS	Mulch	Highest	Residue cover
LPA15NT	PA-15, LBS	No-till	Highest	Residue cover
LOH49CT	OH-49, LBS	Conventional	Highest	Yield
LOH49MT	OH-49, LBS	Mulch	Highest	Yield
LOH49NT	OH-49, LBS	No-till	Highest	Yield
LTYRNCT	Tyrone, LBS	Conventional	Highest	Biomass
LTYRNMT	Tyrone, LBS	Mulch	Highest	Biomass
LTYRNNT	Tyrone, LBS	No-till	Highest	Biomass
LIDEACT	Ideal, LBS Cultivar	Conventional	Highest	Biomass, residue and yield
LIDEAMT	Ideal, LBS Cultivar	Mulch	Highest	Biomass, residue and yield
LIDEANT	Ideal, LBS Cultivar	No-till	Highest	Biomass, residue and yield

* CONV = a conventional type soybean cultivar. Conventional tillage denotes turn plowing.
LBS = a large biomass soybean type.

TABLE 4a. RUSLE soil loss for alternative tillage scenarios (metric units).

		Annual Soil Loss[1]		
Analytical Scenario	C-Factor	Estimate (MTHY)	Difference (MTHY)	Change (%)
Aver. Performance of LBS vs. Conventional Cultivars Under Alternative Tillage Systems				
CAVERCT	0.328	53.8	–	–
LAVERCT	0.301	49.3	−4.5	−8
CAVERMT	0.211	33.6	–	–
LAVERMT	0.173	29.1	−4.5	−13
CAVERNT	0.053	8.5	–	–
LAVERNT	0.037	6.0	2.5	−29
LBS vs. Long-term Conventional Cultivar Under Alternative Tillage Systems				
C35BUCT	0.373	60.5	–	–
LPA15CT	0.311	49.3	−11.2	−19
LOH49CT	0.273	44.8	−15.7	−26
LTYRNCT	0.236	38.1	−22.4	−37
LIDEACT	0.226	35.8	−24.6	−41
C35BUMT	0.296	47.0	–	–
LPA15MT	0.179	29.1	−17.9	−38
LOH49MT	0.149	24.6	−22.4	−48
LTYRNMT	0.119	19.3	−27.8	−59
LIDEAMT	0.108	17.5	−29.6	−63
C35BUNT	0.118	19.0	–	–
LPA15NT	0.035	5.6	−13.4	−71
LOH49NT	0.025	4.0	−15	−79
LTYRNNT	0.015	2.5	−16.6	−87
LIDEANT	0.012	1.9	−17.1	−90
LBS vs. Hutcheson Conventional Cultivar Under Alternative Tillage Systems				
CHUTCCT	0.342	56.0	–	–
LPA15CT	0.311	49.3	−6.7	−12
LOH49CT	0.273	44.8	−11.2	−20
LTYRNCT	0.236	38.1	−17.9	−32
LIDEACT	0.226	35.8	−20.2	−36
CHUTCMT	0.244	40.3	–	–
LPA15MT	0.179	29.1	−11.2	−28
LOH49MT	0.149	24.6	−15.7	−39
LTYRNMT	0.119	19.3	−21.1	−52
LIDEAMT	0.108	17.5	−22.8	−57
CHUTCNT	0.079	12.8	–	–
LPA15NT	0.035	5.6	−7.2	−56
LOH49NT	0.025	4.0	−8.7	−68
LTYRNNT	0.015	2.5	−10.3	−81
LIDEANT	0.012	1.9	−10.8	−85

Analytical Scenario	C-Factor	Annual Soil Loss[1] Estimate (MTHY)	Difference (MTHY)	Change (%)
LBS vs. Williams-82 Conventional Cultivar Under Alternative Tillage Systems				
CWILMCT	0.393	62.7	–	–
LPA15CT	0.311	49.3	−13.4	−21
LOG49CT	0.273	44.8	−17.9	−29
LTYRNCT	0.236	38.1	−24.6	−39
LIDEACT	0.226	35.8	−26.9	−43
CWILMMT	0.322	51.5	–	–
LPA15MT	0.179	29.1	−22.4	−43
LOH49MT	0.149	24.6	−26.9	−52
LTRYNMT	0.119	19.3	−32.3	−63
LIDEAMT	0.108	17.5	−34	−66
CWILMNT	0.140	22.4	–	–
LPA15NT	0.035	5.6	−16.8	−75
LOH49NT	0.025	4.0	−18.4	−82
LTYRNNT	0.015	2.5	−19.9	−89
LIDEANT	0.012	1.9	−20.5	−91

[1]The annual rate of soil loss in metric tons per hectare per year (MTHY) computed by RUSLE (version 1.06).

grain yield, biomass and residue levels (Performance = Lowest) of all the conventional cultivars in the test plots. Based on these observations, we proposed two additional baselines for comparisons. One of these baselines included the highest performing (CHUTCxx) and the other the lowest performing (CWILMxx) conventional soybean cultivars in the test plots. Soil loss for the highest and lowest performing baselines was estimated by re-running the field test plot data through the RUSLE model for scenarios with these cultivars. For instance, the CHUTCCT scenario indicates that soil loss was estimated using values from Hutcheson (CHUTCxx), which produced the highest grain yield, biomass and residue levels of all the conventional (Cxxxxxx) cultivars in the test plots, and a conventional (xxxxxCT) tillage system.

RESULTS AND DISCUSSION

Agronomic characters of increased crop residue for soil erosion control are presented in Tables 1a and 1b. Soil loss estimates for various RUSLE simulation scenarios derived from the data are given in Table 4a and 4b. A comparison of the agronomic characteristics and the soil loss impact of LBS versus conventional soybean is followed by a discussion of soil conservation benefits if the results from the RUSLE simulation of soil erosion are realized. Figures 2a and 2b illustrate the differences in crop residues from LBS versus conventional soybean.

TABLE 4b. RUSLE soil loss for alternative tillage scenarios (U.S. units).

	Annual Soil Loss[1]			
Analytical Scenario	C-Factor	Estimate (USTAY)	Difference (USTAY)	Change (%)
Aver. Performance of LBS vs. Conventional Cultivars Under Alternative Tillage Systems				
CAVERCT	0.328	24.0	–	–
LAVERCT	0.301	22.0	−2.0	−8
CAVERMT	0.211	15.0	–	–
LAVERMT	0.173	13.0	−2.0	−13
CAVERNT	0.053	3.8	–	–
LAVERNT	0.037	2.7	1.1	−29
LBS vs. Long-term Conventional Cultivar Under Alternative Tillage Systems				
C35BUCT	0.373	27.0	–	–
LPA15CT	0.311	22.0	−5.0	−19
LOH49CT	0.273	20.0	−7.0	−26
LTYRNCT	0.236	17.0	−10.0	−37
LIDEACT	0.226	16.0	−11.0	−41
C35BUMT	0.296	21.0	–	–
LPA15MT	0.179	13.0	−8.0	−38
LOH49MT	0.149	11.0	−10.0	−48
LTYRNMT	0.119	8.6	−12.4	−59
LIDEAMT	0.108	7.8	−13.2	−63
C35BUNT	0.118	8.5	–	–
LPA15NT	0.035	2.5	−6.0	−71
LOH49NT	0.025	1.8	−6.7	−79
LTYRNNT	0.015	1.1	−7.4	−87
LIDEANT	0.012	0.8	−7.6	−90
LBS vs. Hutcheson Conventional Cultivar Under Alternative Tillage Systems				
CHUTCCT	0.342	25.0	–	–
LPA15CT	0.311	22.0	−3.0	−12
LOH49CT	0.273	20.0	−5.0	−20
LTYRNCT	0.236	17.0	−8.0	−32
LIDEACT	0.226	16.0	−9.0	−36
CHUTCMT	0.244	18.0	–	–
LPA15MT	0.179	13.0	−5.0	−28
LOH49MT	0.149	11.0	−7.0	−39
LTYRNMT	0.119	8.6	−9.4	−52
LIDEAMT	0.108	7.8	−10.2	−57
CHUTCNT	0.079	5.7	–	–
LPA15NT	0.035	2.5	−3.2	−56
LOH49NT	0.025	1.8	−3.9	−68
LTYRNNT	0.015	1.1	−4.6	−81
LIDEANT	0.012	0.8	−4.8	−85

Analytical Scenario	Annual Soil Loss[1] C- Factor	Estimate (USTAY)	Difference (USTAY)	Change (%)
LBS vs. Williams-82 Conventional Cultivar Under Alternative Tillage Systems				
CWILMCT	0.393	28.0	–	–
LPA15CT	0.311	22.0	−6.0	−21
LOG49CT	0.273	20.0	−8.0	−29
LTYRNCT	0.236	17.0	−11.0	−39
LIDEACT	0.226	16.0	−12.0	−43
CWILMMT	0.322	23.0	–	–
LPA15MT	0.179	13.0	−10.0	−43
LOH49MT	0.149	11.0	−12.0	−52
LTRYNMT	0.119	8.6	−14.4	−63
LIDEAMT	0.108	7.8	−15.2	−66
CWILMNT	0.140	10.0	–	–
LPA15NT	0.035	2.5	−7.5	−75
LOH49NT	0.025	1.8	−8.2	−82
LTYRNNT	0.015	1.1	−8.9	−89
LIDEANT	0.012	0.8	−9.2	−91

[1]The annual rate of soil loss in U.S. tons per acre per year (USTAY) computed by RUSLE (version 1.06).

FIGURE 2a. High crop residues (large biomass soybean).

Agronomic Characters and Economic Returns

Measurements for plant height, dry vegetative biomass, grain yield, and crop residue cover of LBS and conventional (CONV) cultivars are summarized in Tables 1a and 1b, for the years 1994, 1995, and 1998. The three year average data show that LBS soybeans are significantly taller than conven-

FIGURE 2b. Low crop residues (conventional soybean).

tional soybeans. This is the case both at the mean level and the maximum level of plant height for conventional cultivars. LBS produced at least 20 percent more biomass than conventional cultivars on average. Crop residue cover was 31% higher for LBS than conventional soybean after over-wintering and 47% higher after a spring mulch tillage for the 3-year average.

The test data indicated that under farming systems with conventional tillage and continuous soybeans, gross revenues from LBS would be 6.5% lower on average than revenues from conventional soybeans. The reason for lower economic returns was lower grain yield for LBS. However, several LBS lines, in some years, had greater returns than conventional cultivars. For instance, returns from the PA-15 LBS (LBS Maximum Grain Yield) in 1994 were $921 per hectare ($373/acre), 13% more than the mean value of gross returns for conventional cultivars in that year. Returns from this LBS line were even higher in 1994 than returns from Hutcheson, the best overall conventional cultivar in the test. Higher returns resulted from greater grain yields of PA-15. However, this occurred for this LBS line only in 1994. In addition, the PA-15 experimental LBS line produced the highest crop residue percent cover after the double disking mulch tillage operation in most years (data not reported). This suggests that the traits of high yield and long lasting crop residue are being incorporated into LBS lines. By the performance of PA-15 it appears feasible to improve the grain yield of LBS through breeding to a level comparable to the grain yields of conventional cultivars.

Over 30% residue cover on the ground at planting time is the NRCS general target on the average HEL for soil conservation. However, the actual amount of residue cover needed in a specific location on a specific soil varies widely around this 30% residue cover value. In most of the test years, soybean residues from traditional conventional cultivars planted in Maryland in this experiment were observed to be below a 30% crop residue cover target at planting. Column 8 in Tables 1a and 1b shows that crop residue from LBS can easily meet the general conservation target requirement, even after a mulch tillage (double disking) operation. Compared to mean residue for conventional cultivars, the field assessment has shown LBS cultivar residue as 32 percent, 28 percent, and 33 percent higher, respectively, in 1994, 1995, and 1998 measured before the double disking tillage operation (column 7 of Tables 1a and 1b). The corresponding percentage difference increased further to 57 percent, 48 percent, and 55 percent in those years as measured after the double disking tillage operation (column 8 of Table 1a).

These results illustrate that LBS produce more crop residue biomass and contribute more crop residue cover through the next planting than conventional soybean. LBS residues usually last longer than those from conventional soybean. We observed that most of the soybean leaves from soybean canopies had deteriorated by harvest and contributed little to longer term crop residue for soil conservation purposes. The pods had rotted by spring and did not contribute to breaking raindrop impact. The stem and leaf petiole materials continued to be most effective in breaking the impact of raindrops through the next planting cycle. The LBS lines are superior in producing this type of biomass.

Average Performance of LBS versus Conventional Cultivar

Table 4a, block 1 summarizes average soil loss performance of all LBS (LAVERxx) lines versus the average for the conventional cultivars (CAVERxx) used in the field test under the State of Maryland HELs soil loss scenario. The average of all LBSs (LAVERxx) tested would decrease erosion by 8 percent or 4.5 metric tons per hectare per year (MTHY) (2 U.S. tons/A (USTAY)) with planting as conventional tillage, 13 percent or 4.5 MTHY (2 USTAY) with mulch tillage, and 29 percent or 2.5 MTHY (1.1 USTAY) with no-till planting of soybeans, relative to soil erosion estimates for the average of the conventional Maryland type cultivars (CAVERxx) tested. For illustrative purposes, if we assume the country as a whole was similar in erosion potential to the Maryland area, then the planting of LBS could reduce soil erosion by 2.5 MTHY to 4.5 MTHY (1.1 USTAY to 2 USTAY) depending on the planting management practice employed. Using the Maryland soil loss scenario as an illustration, if LBS were used to replace traditional soybean cultivars on 8.1 million hectares (20 million acres) of HEL planted to soybeans, this would save from 20 to 36 million metric tons (22 to 40 million U.S. tons) of soil on U.S. HEL lands per year.

From the RUSLE estimates, we saw a significant benefit in less soil loss for conservation purposes even with the mean of all LBS lines values (Tables 4a and 4b, block 1). However, not all of the (eleven) LBS lines in the experiments expressed the full potential for increased crop residue for soil erosion control. When we determined the decreased soil loss benefits from the "highest performing" (LPA15xx, LOH49xx, LTYRNxx) LBSs or an "ideal" (LIDEAxx) LBS cultivar in relation to the typical (C35BUxx) or a particular conventional (Cxxxxxx) cultivar, the estimated conservation benefits became even greater. Other scenarios represented in Tables 4a and 4b also address these benefits. The use of LBS would greatly facilitate implementation of soil conservation compliance plans because the potential of LBS residues can be calculated 'a priori.'

LBS versus the NRCS Typical Maryland Standard Cultivar

Annual soil erosion estimates for the NRCS typical Maryland standard long-term cultivar (C35BUxx) and various simulation scenarios with experimental test plot data for LBS are presented in Table 4a, block 2 . Using the current NRCS typical Maryland standard long-term cultivar (C35BUxx) as a baseline, annual soil loss estimates using RUSLE predict a soil loss of 60.5 MTHY (27 USTAY) with conventional tillage, 47.0 MTHY (21 USTAY) with mulch tillage, and 19.0 MTHY (8.5 USTAY) with no tillage, respectively. Relative to this baseline case, alternative estimation scenarios for an "ideal" LBS (LIDEAxx) resulted in a reduction in erosion by 41 percent under conventional tillage, 63 percent with a mulch tillage system and 90 percent with a no-till system. For illustrative purposes, using Maryland's soil erodibility conditions, if we assume the planting of the NRCS typical Maryland standard long-term soybean cultivar (C35BUxx) on a projected 8.1 million hectares (20 million A) of HEL in the U.S. were replaced with a soybean embodying the traits of the virtual "ideal" LBS (LIDEAxx) type of soybean, we might expect a total U.S. soil loss reduction in the range of 138 million metric tons/yr. (155 million U.S. tons/yr) to 239 million metric tons/yr (268 million U.S. tons/yr).

The results in Table 4a, column 4 show that for a given simulation scenario with LBS, soil erosion under mulch tillage provided a higher tonnage difference in relation to conventional soybean among the tillage systems. This is probably due to the ability of the LBS types to stay intact in larger pieces when subjected to a mulch tillage operation verses the usual NRCS typical Maryland standard long-term cultivar or other conventional soybean scenarios used as a baseline. Under conventional tillage, the residue of both LBS and conventional cultivar types are largely buried. Under a no-till operation, both types stay intact on the surface without breakage through the next planting. The results of RUSLE seem to indicate that higher biomass production (LTYRNxx = highest residue biomass at harvest) is more important than residue persistence

(LPA15xx = best persistence after spring double disking), in reducing soil erosion. Therefore, the soil conservation performance impacts would become smaller as lines with traits of high biomass (LTYRNxx) production improved toward the "ideal" (LIDEAxx) LBS line. Such an "ideal" LBS cultivar would result in the highest soil conservation benefits. An "ideal" LBS cultivar may be difficult to construct genetically, but data from the experiment show that, in theory, the combined traits would produce the most effective and efficient soil conservation benefit.

LBS versus the Hutcheson Conventional Cultivar

The Hutcheson (CHUTCxx) conventional cultivar has shown higher yields and has a record as a high yielding traditional cultivar in this area of production. It also had the highest biomass and residue of all the conventional cultivars in the test plots. Tables 4a and 4b (continued) results are summarized for various simulation scenarios for LBSs under each tillage system and compared to CHUTCxx. Reduction in soil erosion is primarily due to a higher estimated C-factor for CHUTCxx than the LBS lines. Erosion changes among tillage systems and simulation scenarios for LBS follow the same patterns as discussed in the above section, but the magnitude of soil loss differences are less. The potential gain in soil conservation benefits is smaller if soybean cultivars similar to Hutcheson are compared to LBS.

LBS versus the Williams-82 Conventional Cultivar

The last block of Table 4a reports annual soil loss for the Williams-82 (CWILMxx) conventional cultivar used as a baseline and various estimation scenarios for LBSs under alternative tillage systems. The poorest-performing baseline cultivar used was CWILMxx. Its soil loss as predicted by RUSLE from test data is slightly greater than the soil loss of NRCS typical Maryland standard long-term cultivar (C35BUxx). Soil loss estimates were 62.7 MTHY (28 U.S. tons/A/yr) with conventional tillage, 51.5 MTHY (23 U.S. tons/A/yr) with mulch tillage, and 22.4 MTHY (10 U.S. tons/A/yr) with no tillage, respectively. Comparing the "ideal" (LIDEAxx) LBS with CWILMxx used as a baseline resulted in soil erosion estimates decreasing 43 percent with conventional tillage, 66 percent with mulch tillage, and 91 percent with no tillage, respectively. The higher soil erosion difference from the "ideal" (LIDEAxx) LBS soybean was primarily due to the lower level of crop residue biomass produced by Williams-82. Williams-82 had the highest C-factor values for each tillage scenario. The data indicate that potential gain in soil conservation benefits from enhancing residues is greater as cultivars with a lower level of crop residue biomass, like Williams-82, are replaced by LBS, and less when LBS replace cultivars like Hutcheson.

Experimental observations and experience from increasing seeds from the released forage type LBS cultivar, Tyrone, indicate little need for modifications in harvesting equipment. Compared to the cultivation of the conventional cultivar Hutcheson, major changes in crop management practices are not expected. Accordingly, variable costs of the LBS production were assumed to be the same as that of the conventional soybean production.

SUMMARY AND CONCLUSIONS

U.S. farmers are growing soybean crops on more than eight million hectares (20 million acres) of highly erodible lands (HEL), approximately one third of the total soybean acreage. Conservation efforts, including higher crop residues, are required on HEL by conservation compliance policy in the three latest Farm Bills enacted by the U.S. Congress. A project at the Beltsville Agricultural Research Center, in Beltsville, Maryland, explored the possibility of enhancing soil conservation methods by using soybeans bred for increased crop residues. Several of the test lines are as tall as 1.5 to 1.8-meter (5 to 6 ft) and produced soybean crop residue coverage above the NRCS 30-percent general coverage "target" for HEL. This study evaluated the soil conservation impacts of LBS versus conventional soybean cultivars using experimental field plot data. Soil loss impact was estimated using RUSLE. Conventional soybean cultivars were used as a base for comparison. This included baselines for typical long-term soybean values used by NRCS for the State of Maryland, and highest-performing, lowest-performing, and average of conventional cultivars in the test plots.

Compared to conventional soybean, gross revenues from LBS were about 2 percent to 10 percent lower because of lower grain yields of the experimental LBS (Table 1a & 1b). However, LBSs produced more crop residue than conventional soybeans. The mean of LBS showed an increase of soil coverage by 31 percent before mulch tillage and an increase of 47 percent after mulch tillage relative to the mean of conventional cultivars in the test. The study indicated that improving grain yield along with enhancing soybean crop residue is a desirable goal for soybean breeding. Soybean cultivars with high grain yields as well as enhanced soybean crop residue are needed on the nation's soybean lands to provide reduced onsite and offsite damage due to soil erosion and a reasonable cash income to growers.

Compared to any baselines established with conventional soybeans from the typical state average and the cultivars in this test, LBS reduced soil erosion significantly. Reduction in soil erosion tonnage provided the greatest difference with a mulch tillage system when comparing LBS to conventional soybean. The conservation impact between the highest-biomass LBS and "ideal" LBS cultivar scenario was comparable. This indicates that residue persistence through a spring mulch tillage operation is less important to soil loss than high biomass according to the RUSLE model. However, in practice it would appear that LBS lines with highest retention of residues on the surface after mulch tillage would do a better job of meeting or exceeding the "target" levels mandated by NRCS at spring planting. Social benefits and offsite damage factors were not determined by this study. Increased onsite productivity due to reduced soil loss and increased soil fertility also were not determined. Obviously any beneficial changes in these factors would have positive effects on the economy and the environment. The most positive consideration in planting LBS types of soybean would be that the soil conservation benefit is potentially achievable without drastically altering current soybean production and cropping systems.

Currently, the LBSs evaluated in these tests may not be sufficiently advanced for widespread, large scale farm production of grain. Additional improvement of LBS for grain production is needed to merit use on farms. Cultivars need to be fully perfected and extensively tested before LBS can become a major source of crop residue production for soil conservation efforts. However, sufficient data on the crop residue performance of LBSs has been collected by this experimental test study to predict the potential conservation benefits of LBS. Some questions are still unanswered. Are management requirements for producing LBS higher than those for conventional soybean cultivars? Can LBS be bred to consistently produce grain yields comparable to the grain yields of conventional soybean cultivars over a wide growing region? Can the farmer finish planting preparation without interfering with other crop rotations? Does the farmer need specialized or modified equipment to harvest LBS? Will there be an increased energy cost in harvesting LBS? LBS must prove to be economically profitable and environmentally sound. If the farmer cannot harvest a yield of grain equal in quality and quantity to his conventional soybeans, then it will not be profitable for him to plant LBS in his crop rotation systems. However, if LBSs produce higher residues compared to conventional soybean cultivars, a lower yield may be acceptable to the farmer if conservation plans would allow the planting of LBS crops more often than conventional cultivars. Quite often a particular soil district's conservation plans will limit soybean production to no more than 1 in 2 or 1 in 3 years in the crop rotation sequence. Higher residue amounts contributed by LBS might allow these restrictions to be relaxed. If planting of LBS were to become an option crop on HEL soybean lands, then the RUSLE typical C factor values for soybeans in each region would have to be adjusted for this new type of crop. The successful adoption of a newly designed crop depends upon the level of farmers' interest in growing LBS to assist with the nation's soil conservation efforts. Before LBS can become a source of crop residues for soil conservation on a large scale, they must prove to be both economically profitable and environmentally beneficial in sustaining the soil resource.

The traits for increased crop residue production in LBS were first developed in soybean lines bred for soybean forage production. Three of the LBS lines, Tyrone, Derry, and Donegal, have been released by the USDA as cultivars to be used for forage production. The LBS forage lines had not been under breeding regimes that focused solely on improving grain yields. However, they were selected for the capacity to produce seed with sufficient efficiency to provide seed stocks for forage producers at reasonable prices. Multi-purpose types of LBS, such as the forage LBS types, could “fit the bill” for increasing crop residue needs on 1/3 of the nation’s soybean acreage. Improvements of the LBS type of soybean for higher grain yield should be beneficial and profitable. The large biomass accumulation of LBS will also result in more organic carbon sequestration in soybean hectare (acreage) soils and help with the balance of carbon efforts in our biosphere. According to the results of this study, soil conservation efforts will benefit significantly from the improved crop residue production characteristics that are found in the LBS lines.

REFERENCES

Bangsund, D.A. and Leistritz, F.L. 1999. Economic contribution of the soybean industry to North Dakota. Department of Agricultural Economics, North Dakota State University, Fargo, North Dakota, Agricultural Economic Report No. 416.

Devine, T.E. and Hatley, E.O. 1998a. Registration of ‘Donegal’ forage soybean. Crop Sci. 38:1719-1720.

Devine, T.E., Hatley, E.O. and Starner, D.E. 1998b. Registration of ‘Derry’ forage soybean. Crop Sci. 38:1719.

Devine, T.E., Hatley, E.O. and Starner, D. E. 1998c. Registration of ‘Tyrone’ forage soybean. Crop Sci. 38:1720.

Foster, G.R., Renard, K.G., Yoder, D.C., McCool, D.K. and Weesies, G.A. 1996. RUSLE User’s Guide. Soil & Water Cons. Soc. 173 pgs.

Lee, J. 1997. New soybeans fill tofu niche. Agric. Research 45:13.

McMurtrey, J.E. and Devine, T.E. 1997. Increased crop residue with giant soybeans. National Conservation Tillage Digest, March Issue.

Minnesota Soybean Growers Association (MSGA). 1998. Soy goes mainstream. Press release, Minnesota Soybean Growers Association, North Mankato, MN, April 28.

United Nation, Food and Agriculture Organization (FAO). 1999. Agricultural Production. http://apps.fao.org/cgi-bin/nph-db.pl?subset=agriculture

U.S. Department of Agriculture. 1997. Agricultural resources and environmental indicators: 1996-97. Economic Research Service, U.S. Department of Agriculture, Washington, DC, July.

U.S. Department of Agriculture. 1998. Oil crops outlook. Economic Research Service, U.S. Department of Agriculture, Washington, DC, July.

U.S. Department of Agriculture. 1999. Agricultural Statistics 1998. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, DC.

U.S. Department of Agriculture. 2003. Agriculture Research Service, National Sedimentation Laboratory. Revised universal soil loss equation (RUSLE), http://www.sedlab.olemiss.edu/rusle/index.html

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